

Design and construction of a triggered spark gap for long distance exploding wire experiments

Rowan Sinton, Ryan van Herel, Dr. Wade Enright, Prof. Pat Bodger
Department of Electrical and Computer Engineering
University of Canterbury
New Zealand

Abstract— This paper gives the technical information required to build a triggered spark gap (TSG) for igniting exploding wire experiments. The TSG, which uses a concentric three-electrode configuration, reliably triggers on test voltages between 10 and 60 kVdc from a 21 μ F capacitor bank discharge source. A description of the electronic triggering circuit, operating region and a set of experimental results obtained using the TSG are also given.

Keywords—Exploding wire; triggered spark gap

I. INTRODUCTION

High voltage research at the University of Canterbury is presently investigating the applications of plasma as a high-voltage winding conductor. Plasma conductors of up to 10 meters in length and plasma coils have been created [1, 2]. A technique using exploding wire (EW) creates the conductive plasma paths in the standard atmospheric conditions of the high voltage laboratory.

Formation of the plasma conductors is due to the special breakdown mechanisms found in the electrical explosion of enamelled copper wires, which are 0.2 – 0.3mm in diameter. Literature to date only describes EW of short lengths – usually much less than one metre [3]. Such short conductor lengths are not suitable for forming into a high-voltage winding. An experimental setup for investigating much longer conductor lengths (up to 10 metres) is necessary. A crucial aspect of this is the high voltage switch that initiates the wire explosion.

The circuit used for EW experiments at the University of Canterbury was built by Smith et al, and the details of its construction and operation are described in [4]. A large capacitor bank (21 μ F) is charged to a voltage of between 10 and 60 kVdc, and then switched on to the test wire. The current that flows can be as large as 20 kA. The switching mechanism used by Smith was found to be unsuitable for the requirements of more detailed research into the EW, and as such has been replaced with the one described in this paper. The switch to perform this task must be safe for the operators and equipment, reliable over the full range of required experimental parameters, and capable of withstanding hundreds of experiments before requiring maintenance.

There were no commercially available products that met the above requirements, and so a triggered spark gap (TSG) type switch was designed, constructed and tested (fig. 1). The details of how this was done, justification for design choices

and results of actual experiments using this switch are presented in this paper.

II. TRIGGERED SPARK GAP DESIGN

A. Voltage and Current Ratings

The switch was required to operate reliably through the range of experimental voltages (in this case, 10 – 60 kVdc). The gas medium in the gap was to be atmospheric pressure air, for ease of manufacture and maintenance. The voltage range determined the range of gap lengths, sphere size, and also the insulation from earth of the whole unit. Standard sphere-gap tables indicated that an appropriate sphere diameter was 50 mm, with gap lengths from 6 mm to 50 mm [1]. Adjustment was provided by a large nut on the threaded rod supporting one of the spheres.

The switch was expected to transfer energies of up to 38.5 kJ in times of less than 100 μ s, which could give instantaneous load power of up to 385 MW. Peak currents of 20 kA were expected. Although of short duration, these currents can cause severe damage (pitting) to the sphere surfaces. The spheres were therefore designed for easy removal for maintenance. Brass has proven to be a suitably resilient material for the sphere surface.

B. Operating Region

The operating region of a triggered spark gap is defined as the voltage range for a given gap length in which it can reliably be triggered without risking flashing over prematurely, or ‘self-triggering’. If the TSG self-triggers, it will not only destroy the experiment but it can also damage charging equipment. Nevertheless, it is important that all equipment and personnel present are prepared for such a self-triggering event.

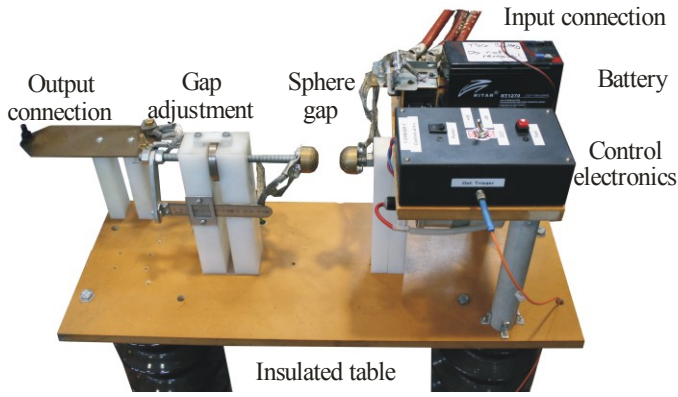


Figure 1. Photograph of the finished TSG.

To achieve a wide operating region, the electrode configuration must be carefully designed such that the triggering spark is maximally effective. It is crucial that the triggering spark is not obscured from the main gap so that ultraviolet light and ionized particles can contribute to the breakdown process. A good solution is to have the triggering electrode concentric to one of the spheres, such that the triggering spark appears perpendicular and unobstructed to the main gap. This was implemented by threading a silicon-insulated cable through an axial hole in the sphere and mounting rod (fig. 2).

C. Jitter

The variation in triggering delay is called the jitter. It is preferable to minimize the jitter, and so ensure that instrumentation can be triggered reliably and results are repeatable. In many TSG applications, jitter time is critical and values as low as 50 ns are not uncommon.

The main cause of jitter in this TSG design was due to the magnitude of electric field in the main gap. If the gap is set close to the self-triggering distance, the trigger delay will be very fast – around 30 μ s. However, if the voltage is very low for the set gap length, the delay may be as much as 2 ms. In the formation of long distance plasma conductors, the experiment duration is hundreds of microseconds so jitter times of 10 to 100 μ s are acceptable.

D. Triggering electronics

The triggering spark in this design was provided by an automotive ignition coil. This inexpensive, easily obtained item can produce a triggering spark up to 5 mm long, and has proven to be extremely reliable over many hundreds of shots. The ignition coil is driven by a 12 V supply which is switched by a high-power MOSFET. The spark is generated when the MOSFET is switched off, causing an inductive voltage across the coil. The transient overvoltage seen by the MOSFET must be limited by a snubbing circuit; a parallel capacitor and transient voltage suppressor (TVS) diode is adequate protection (fig. 3).

E. Isolation

The TSG was to be placed at the high voltage side of the circuit, so that the wire specimen would not be live while the capacitors were charged. This is necessary not only to eliminate a potential hazard to the operators, but also to eliminate audible corona on the wire. In this way, the test circuit is normally quiet during charging. If corona is heard, the operators safely shut down the experiment and investigate the corona source.

The TSG triggering circuit is therefore at high voltage, and must be powered and signaled in an electrically isolated manner. To achieve isolation of the power supply, a 12 V lead-acid battery was used. The negative rail of the battery and triggering electronics were connected to the high voltage sphere of the main gap. The triggering signal was delivered via a fiber-optic cable, which was considered to be more reliable in the high voltage lab environment than alternatives such as infrared or radio-frequency methods.

F. Maintaining Ionisation

For the application of creating plasma conductors, the TSG must remain ionized for the duration of the experiment. The experiments, by nature, have long periods of negligible conduction. At least 1 A must continuously flow to ensure the switch reliably remains in the ‘on’ state. A 30 k Ω water resistor to ground was connected to the EW side of the TSG. This was proven to be sufficient by observing that an arc remained in the TSG for several seconds after triggering.

The water resistor serves a secondary purpose – to remove the excess energy from the capacitors after the experiment. The water resistor was designed with enough volume to dissipate the full 38.5 kJ of capacitor energy with moderate temperature rise.

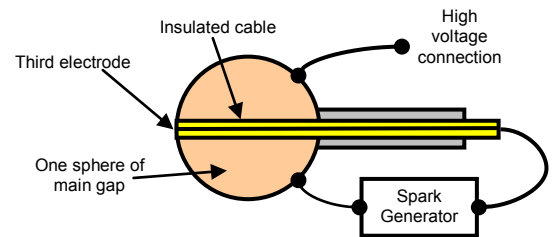


Figure 2. One of the spheres with the triggering electrode.

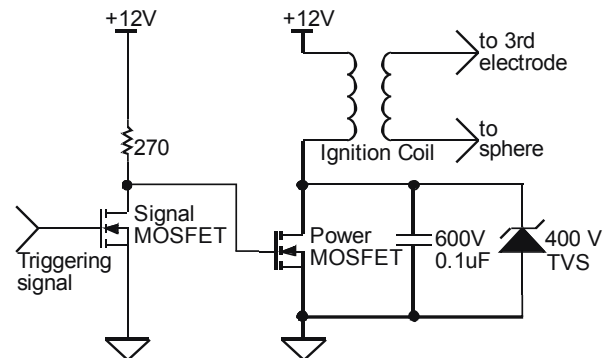


Figure 3. Simplified triggering circuit schematic.

III. RESULTS

The TSG was tested over the full range of voltages, producing an operating chart with which to set the gap length (fig. 4). The operating region was considered to be sufficient, as it allowed for a minimum 10 kV margin between the minimum-triggering and self-triggering voltages.

Voltage waveforms (fig. 5) recorded during the EW experiments performed while using the TSG proved that the TSG was switching correctly. Conduction (denoted by a drop in capacitor voltage) can be continued even after a period of up to 200 μ s of almost no current flow – i.e. the TSG remains in an ‘on’ state. The detail of the switching of these experiments (fig. 5(b)) shows that triggering was consistent, even though the voltage (and consequently the gap length) is varied through a very large range of 10 to 60 kVdc.

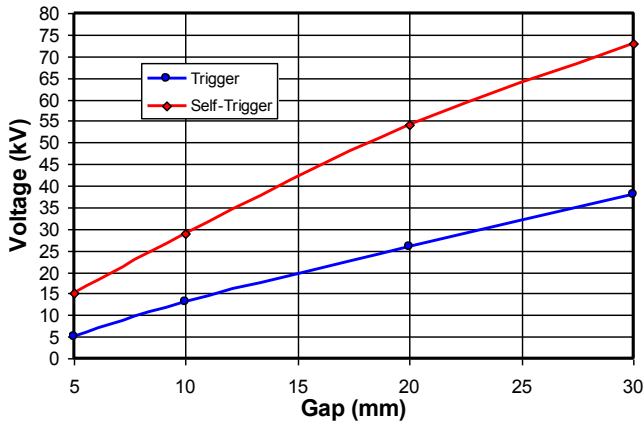


Figure 4. The operating graph for the TSG.

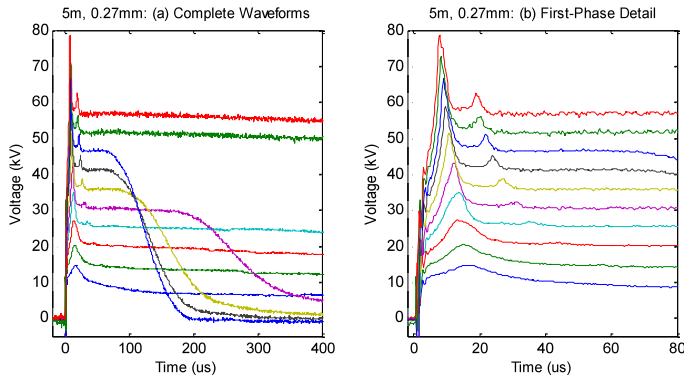


Figure 5. Voltage traces from plasma conductor experiments. Identical wires are used in each test, but the voltage is varied from 10 kV to 60 kV. Plasma conductors are formed in the four voltage traces (left) that fall to nearly 0 V.

The reliable nature of the TSG allowed a high turn-around rate of experiments. Up to 10 experiments per hour can now be performed, meaning that more evidence of the long distance EW phenomena can be obtained.

In addition, the TSG has allowed coordination of accurate timing of a photographic camera, producing highly informative photographs of EW phenomena. A ‘streak’ photograph was obtained using the precise timing of the mechanical shutter of a digital single lens reflex (DSLR) camera (fig. 6). The camera orientation was such that the shutters formed a slit, moving horizontally along the axis of the wire, left to right. In the resulting image one can see rapidly expanding plasma which forms into a bright plasma conductor, and then the remaining clouds of copper gas. Approximately 2 ms of time is represented in the horizontal axis of the photograph.

IV. CONCLUSIONS

Experiments in creation of long distance plasma conductors have been improved with the implementation of the TSG described in this paper. The TSG operates reliably through the range of experimental voltages (10 – 60 kVdc). It is now possible to trigger the high voltage impulse from the capacitor bank, while coordinating photography and improving the turn-around rate between experiments. This has improved empirical data available to researchers.

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Figure 6. A streak photograph of a restriking wire.